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The Electric and Hybrid Vehicle Program was conducted under the guidance of the then Energy Research and Development Administration (ERDA), now part of the Department of Energy.

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ELECTRIC PASSENGER VEHICLE

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SUMMARY

The EPC Hummingbird, an electric passenger vehicle manufactured by Electric Passenger Cars, Inc., of San Diego, California, was tested at the Dynamic Science Test Track in Phoenix, Arizona, between March 23 and April 26, 1977. The tests are part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. The Hummingbird vehicle performance test results are presented in this report.

The Hummingbird vehicle is a converted four-passenger Volkswagen "Thing" powered by 12 heavy-duty, lead-acid batteries. The rear-mounted internal combustion engine has been replaced with an electric motor made by modifying an aircraft generator. The motor shaft is connected to the drive train through the conventional Volkswagen 4-speed manual transaxle, including the clutch. The controller is a transistorized chopper with current limiting and thermal overload protection. The braking system is a conventional Volkswagen hydraulic braking system. Regenerative braking was not provided.

All tests were run at the gross vehicle weight of 1463 kilograms (3225 lbm). The results of the tests are as follows:

Test condition (constant speed or driving schedule)		Type of test						
		Range		Road power, kW	Road energy		Energy consumption	
km/h	mph	km	mile		MJ/km	kWh/mile	MJ/km	kWh/mile
40	25	56.5	35	2.95	0.27	0.12	1.23	0.55
56	35	36.8	23	6.45	.29	.13	1.61	.72
B		37.2	20	----	----	----	1.86	.83

The Hummingbird was able to accelerate from 0 to 32 kilometers per hour (0 to 20 mph) in 9.4 seconds and from 0 to 48 kilometers per hour (0 to 30 mph) in 22 seconds. The gradeability limit was 22 percent.

INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on September 17, 1976. The law requires the Energy Research and Development Administration (ERDA) to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline (1) to compare improvements in electric and hybrid vehicle technologies, (2) to assist in establishing performance standards for electric and hybrid vehicles, and (3) to help guide future research and development activities.

The National Aeronautics and Space Administration (NASA), under the direction of the Electric and Hybrid Research, Development, and Demonstration Office of the Division of Transportation Energy Conservation of ERDA, has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies. The tests were conducted according to the ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure ERDA-EHV-TEP, described in appendix E of reference 1. This procedure is based on the Society of Automotive Engineers (SAE) J227a procedure (ref. 2). Seventeen electric vehicles have been tested under this phase of the program, 12 by NASA, 4 by MERADCOM, and 1 by the Canadian government.

The assistance and cooperation of Electric Passenger Cars, Inc., the vehicle manufacturer, is greatly appreciated. The Energy Research and Development Administration provided funding support and guidance during this project.

U.S. customary units were used in the collection and reduction of data. The units were converted to the International System of Units for presentation in this report. U.S. customary units are presented in parentheses. The parameters, symbols, units, and unit abbreviations used in this report are listed here for the convenience of the reader.

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Parameter	Symbol	SI units		U.S. customary units	
		Unit	Abbreviation	Unit	Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mph/s
Area	---	square meter	m^2	square foot; square inch	ft^2; in^2
Energy	---	megajoule	MJ	kilowatt hour	kWh
Energy consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Energy economy	---	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Force	P	newton	N	pound force	lbf
Integrated current	---	ampere hour	Ah	ampere hour	Ah
Length	---	meter	m	inch; foot; mile	in.; ft; ---
Mass; weight	W	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	---	kilopascal	kPa	pound per square inch	psi
Range	---	kilometer	km	mile	---
Specific energy	---	megajoule per kilogram	MJ/kg	watt hour per pound	Wh/lbm
Specific power	---	kilowatt per kilogram	kW/kg	kilowatt per pound	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mph
Volume	---	cubic meter	m^3	cubic inch; cubic foot	in^3; ft^3

OBJECTIVES

The objectives of the tests were to measure vehicle maximum speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, gradeability limit, road energy consumption, road power, indicated energy consumption, braking capability, battery charger efficiency, and battery characteristics for the Hummingbird electric vehicle.

TEST VEHICLE DESCRIPTION

The Hummingbird is a converted four-passenger Volkswagen "Thing" powered by 12 heavy-duty, lead-acid battery modules. The rear-mounted internal combustion engine has been replaced with an electric motor made by modifying an aircraft generator. The motor shaft is connected to the wheels through a conventional Volkswagen 4-speed manual transaxle, including the clutch. The controller is a transistorized chopper with a 400-ampere current limit and thermal overload protection. The vehicle is driven in a conventional manner, with an accelerator pedal to increase power, a clutch to shift gears, and a conventional pedal to activate the hydraulic brakes. No regenerative braking was provided on this vehicle. The vehicle is shown in figure 1 and a detailed description is given in appendix A. A 230/208-volt off-board charger was provided to charge the traction battery. A 120-volt on-board charger was provided to charge the accessory battery.

INSTRUMENTATION

The Hummingbird was instrumented to measure vehicle speed and range, battery current and voltage, motor current, temperatures of the motor frame and front and rear battery packs, and battery charger power. A schematic diagram of the electric propulsion system is shown in figure 2.

A Nucleus Corporation Model NC-7 precision speedometer (fifth wheel) was used to measure vehicle velocity and distance traveled. Auxiliary equipment used with the fifth wheel included a Model ERP-X1 electronic pulser for distance measurement, a Model NC-PTE pulse totalizer, a Model ESS/E expanded-scale speedometer, and a programmable digital attenuator. The fifth wheel was calibrated before each test by rotating the wheel on a constant-speed, fifth-wheel calibrator drum mounted on the shaft of a synchronous alternating current (AC) motor. The accuracy of the distance and velocity readings was within ± 0.5 percent of the readings.

The integrated battery current was measured for the battery packs with a current shunt and an on-board current integrator. It was recorded manually after each test and after each battery charge cycle. This measurement provides the ampere-hours delivered from and returned to the battery pack. In addition, battery electrolyte temperatures and specific gravities were measured manually before and after both the test runs and the charge cycles. The current integrator is a Model SHR-C3 Curtis current integrator and was calibrated periodically to within ± 1 percent of reading.

The vehicle speed and distance pulses were recorded on a Honeywell 195 Electronik two-channel, strip-chart recorder. The battery current and voltage were also recorded on a Honeywell 195 recorder during the charge cycle. The accuracy of this model recorder is better than 0.5 percent.

In addition to battery voltage, current, and ampere-hours recorded during the charge cycle, the energy delivered to the charger was measured with a General Electric 1-50A single-phase residential kilowatt-hour meter. During one charge series, charger efficiency was measured with a laboratory-type wattmeter with Hall-effect current sensors that was manufactured by Ohio Semitronics, Inc.

Motor current was measured to determine motor performance during operation. An 800-ampere current shunt was used. The current was displayed on an analog meter mounted on the vehicle instrument panel.

Motor frame and battery pack temperatures were sensed with iron-constantan thermocouple probes. These were wired through a three-position selector switch for display on an analog meter.

Power for the fifth wheel and current integrator was provided from a 12-volt starting, lighting, and ignition (SLI) battery. A Tripp Lite 500-watt DC/AC inverter provided the alternating-current power.

All instruments were calibrated periodically. The integrators and strip-chart recorders were calibrated with a Hewlett-Packard Model 6920 B meter calibrator, which has an accuracy of 0.2 percent of reading and a usable range of 0.01 to 1000 volts.

TEST PROCEDURES

The tests described in this report were performed at the Dynamic Science Test Track, a two-lane, 3.22-kilometer (2-mile) asphalt track located in Phoenix, Arizona. A complete description of the track is given in appendix B. When the vehicle was delivered to the test track, the pretest checks described in appendix C were conducted. The first test was a formal shakedown to familiarize the driver with the operating characteristics of the vehicle, to check out all instrumentation systems, and to determine the vehicle's maximum speed. All tests were run in accordance with the ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure ERDA-EHV-TEP, appendix E of reference 1, at the gross vehicle weight of 1463 kilograms (3225 lbm).

Range Tests at Constant Speed

The vehicle speed for the highest constant-speed range test was determined during checkout tests of the vehicle. It was specified as 95 percent of the minimum speed the vehicle could maintain on the test track when it was traveling at full power. This speed was 64 kilometers per hour (40 mph) for the Hummingbird vehicle. The maximum speed of this vehicle was subsequently reduced to 56 kilometers per hour (35 mph) when tests showed that 64 kilometers per hour (40 mph) could not be maintained without overheating the motor.

Range tests at constant speeds were run at 40 and 56 kilometers per hour (25 and 35 mph). The speed was held constant within ±1.6 kilometers per hour (1 mph), and the test was terminated when the vehicle could no longer maintain 95 percent of the test speed. The range tests were run at least twice at both speeds.

Range Tests under Driving Schedules

Only the 32-kilometer-per-hour (20-mph), schedule B stop-and-go driving cycle, shown in figure 3, was run with this vehicle. The Hummingbird was unable to accelerate rapidly enough to meet the requirement for schedule C. A complete description of cycle tests is given in appendix E of reference 1. A special instrument, called a cycle timer, was developed at the Lewis Research Center to assist in accurately running these tests. Details of the cycle timer are given in appendix C. The cycle tests were terminated when the test speed could not be attained in the time required under maximum acceleration.

Acceleration and Coast-Down Tests

The maximum acceleration of the vehicle was measured on a level road with the battery fully charged and 40 and 80 percent discharged. Four runs, two in each direction, were conducted at each of these three states of charge. Depth of discharge was determined from the number of ampere-hours removed from the batteries. Acceleration runs were made on the southern straight section of the track, and coast-downs on the northern straight section (appendix B, fig. B-1). Coast-down data were taken with the transmission in neutral after completion of the acceleration test and with fully charged batteries in order to start the coast-down run from the maximum attainable vehicle speed.

Braking Tests

Braking tests on the vehicle were conducted

(1) To determine the minimum stopping distance in a straight-line emergency stop

(2) To determine the controllability of the vehicle while braking in a turn on both wet and dry pavement

(3) To determine the brake recovery after the vehicle was driven through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes

(4) To determine the parking brake effectiveness on an incline

Instrumentation used during the braking test included a fifth wheel programmed to determine stopping distance, a brake pedal force transducer, and a decelerometer. A complete description of the braking tests is given in the discussion of test results and in appendix E of reference 1.

Tractive Force Tests

The maximum grade climbing capability of the test vehicle was determined from tractive force tests by towing a second vehicle. The driver of the towed vehicle, by applying the footbrake, maintained a speed of about 3 kilometers per hour (2 mph) while the test vehicle was being driven with a wide-open throttle. The force was measured by a 13 000-newton (3000-lbf) load cell attached to the tow chain between the vehicles. The test was run with the batteries fully charged and 40 and 80 percent discharged.

Charger Efficiency Tests

Two methods were used to determine charger efficiency as a function of charge time. In the first method a residential kilowatt-hour meter was used to measure input power to the charger by counting rotations of the disk and applying the meter manufacturer's calibration factor. The charger output power was determined by multiplying the average value of current by the average value of voltage. Residential kilowatt-hour meters are calibrated for sinusoidal waves only. The error in measuring input power depends on the wave shape and may be as high as 5 percent. The method of determining output power is correct only when either the voltage or the current is a constant during each charging pulse. The battery voltage does change during each charging pulse, which introduces a small error. The current shunts used to measure current are inaccurate for pulsing current. The error depends on frequency and wave shape and may exceed 10 percent.

In the other method used for determining charger efficiency a 50-kilowatt power meter was used on both the input and output of the charger and a Hall-effect current probe was used for current measurements. To minimize errors, the same meter and current probe were used for both the input measurement and the output measurement. The average power measured was about 4 percent of full scale.

TEST RESULTS

Range

The data collected from all the range tests are summarized in table I. Shown in the table are the test date, the type of test, the environmental conditions, the range test results, the ampere-hours into and out of the battery, and the energy into the charger. These data were used to determine vehicle range, battery efficiency, and energy consumption.

During most of the test period, the winds were variable and gusty. Even though the wind speed was less than 16 kilometers per hour (10 mph), on several occasions the wind was blowing in different directions and at different velocities at two positions on the track. There was no indication that this variation in wind velocity significantly affected the range or other test results as long as the measured winds were less than about 16 kilometers per hour.

The maximum speed of the vehicle was measured during the checkout tests. It is defined as the average speed that could be maintained on the track under full power. The measured maximum speed was 68 kilometers per hour (42 mph) for this vehicle. This differs from the maximum speed used in the range tests.

Three 40-kilometer-per-hour (25-mph), two 56-kilometer-per-hour (35-mph), and two schedule B range tests were run. All the test results are shown in table I.

Maximum Acceleration

The maximum acceleration of the vehicle was determined with the batteries fully charged and 40 and 80 percent discharged. Vehicle speed as a function of time is shown in figure 4 and table II. The average acceleration $\bar{a}_n$ was calculated for the time period t_{n-1} to t_n, where the vehicle speed increased from V_{n-1} to V_n, from the equation

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed of the vehicle $\bar{V}$ from the equation

$$\bar{V} = \frac{V_n + V_{n-1}}{2}$$

Maximum acceleration as a function of speed is shown in figure 5 and table II.

Gradeability

The maximum specific grade, in percent, that a vehicle can climb at an average vehicle speed $\bar{V}$ was determined from maximum acceleration tests by using the equations

$$G = 100 \tan (\sin^{-1} 0.1026\ \bar{a}_n) \qquad \text{for V in km/h}$$

in SI units

or

$$G = 100 \tan (\sin^{-1} 0.0455\ \bar{a}_n) \qquad \text{for } \bar{V} \text{ in mph}$$

in U.S. customary units

where $\bar{a}_n$ is average acceleration in meters per second squared (mph/sec). The maximum grade the Hummingbird can negotiate as a function of speed is shown in figure 6 and table II.

Gradeability Limit

Gradeability limit is defined by the SAE J227a procedure as the maximum grade on which the vehicle can just move forward. The limit was determined by measuring the tractive force with a load cell while towing a second vehicle at about 3 kilometers per hour (2 mph). It was calculated from the equations

$$\text{Gradeability limit in percent} = 100 \tan \left(\sin^{-1} \frac{P}{9.8\ W} \right)$$

in SI units

or

$$\text{Gradeability limit in percent} = 100 \tan \left(\sin^{-1} \frac{P}{W} \right)$$

in U.S. customary units

where

P tractive force, N (lbf)

W gross vehicle weight, kg (lbm)

The Hummingbird was capable of exerting the following tractive forces for three states of battery discharge:

(1) Fully charged, 3069 newtons (690 lbf)

(2) 40 Percent discharged, 2936 newtons (660 lbf)

(3) 80 Percent discharged, 2802 newtons (630 lbf)

At a vehicle weight of 1463 kilograms (3225 lbm) the resulting gradeability limits were

(1) Fully charged, 22 percent

(2) 40 Percent discharged, 21 percent

(3) 80 Percent discharged, 20 percent

Road Energy Consumption

Road energy is a measure of the energy consumed per unit distance in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the portion of the transmission rotating when in neutral. It was obtained during coast-down tests, when the differential was being driven by the wheels, and thus may be different than the energy consumed when the differential is being driven by the motor.

Road energy consumption E_n was calculated from the following equations:

$$E_n = 2.78 \times 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ MJ/km}$$

or

$$E_n = 9.07 \times 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ kWh/mile}$$

where

W vehicle mass, kg (lbm)

V vehicle speed, km/h (mph)

t time, s

Vehicle speed as a function of time during coast-down is shown in figure 7 and table III, and the results of the road energy calculations are shown in figure 8 and table III.

Road Power Requirements

The calculation of road power is analogous to the calculation of road energy. It is a measure of the power needed to overcome vehicle aerodynamic and rolling resistance plus the power losses from the differential, the drive shaft, and a portion of the transmission. The road power P_n required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86\times10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ kW}$$

or

$$P_n = 6.08\times10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ hp}$$

The results of road power calculations are shown in figure 9 and table III.

Indicated Energy Consumption

The vehicle indicated energy consumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test, where the energy is the input to the battery charger.

The energy input to the battery charger was measured with a residential kilowatt-hour meter after each range test. Substantial overcharge of the batteries was usually required in order to assure that all battery cells were fully charged and that the pack was equalized. The reported energy usage may be higher than would be experienced with normal vehicle field operation. Indicated energy consumption as a function of vehicle speed is presented in figure 10 and table IV for the constant-speed tests.

Braking Capability

Simplified braking capability tests were conducted according to the procedure outlined in appendix E of reference 1 in order to provide a preliminary evaluation of the vehicle's braking capabilities. The procedure also includes tests for handling, but at ERDA's direction they were not conducted on this vehicle.

Straight-line stops. - Six straight-line stops from 56 kilometers per hour (35 mph) were made, three from each direction. Stopping distance varied from 14.0 meters (46 ft) to 16.2 meters (53 ft).

Stops on a curve. - Three stops were made going into a 0.3-g curve from 56 kilometers per hour (35 mph) on dry pavement turning right, and three stops were made on the same curve turning left. No difficulties were encountered in stopping within the 3.6-meter (12-ft) lane. The stopping distance varied from 23.3 meters (71 ft) to 26.6 meters (81 ft). The tests were repeated in a 0.2-g turn on wet pavement. Again the vehicle stopped smoothly with no problems. The stopping distances varied from 26.2 meters (80 ft) to 28.5 meters (87 ft).

Wet brake recovery. - Three baseline stops were made from 48 kilometers per hour (30 mph) with dry brakes, decelerating at 3 meters per second squared (10 ft/sec^2). The average pedal force was 191 newtons (43 lbf). After driving through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes, the tests were repeated. The first stop was made with a pedal force of 196 newtons (44 lbf). The brakes showed no signs of fading after the brake soak.

Parking brake. - Tests were conducted to determine parking brake effectiveness. The braking force required to hold the vehicle on a 30-percent slope was 356 newtons (80 lbf) facing uphill and 222 newtons (50 lbf) facing downhill, with the force being applied 3.8 centimeters (1.5 in.) from the top of the brake handle. No slippage during the 5-minute hold was observed with the parking brake set as described. The test was run twice in each attitude.

COMPONENT PERFORMANCE AND EFFICIENCY

Battery Charger

The battery charger furnished with the Hummingbird was a Model 72S2T12 charger manufactured by Lester Equipment Manufacturing Co., Inc. When this unit failed, it was replaced by a Lester Model 72LE26ET charger. Both chargers operated on 230-volt, single-phase input. Output was through a center-tapped transformer connected through diodes to produce full-wave rectification. Output was nominally rated at 72 volts and 26 amperes, with a peak current limit of 30 amperes. An adjustable 12-hour timer controlled the charge cycle on the 72S2T12. The 72LE26ET incorporated automatic shutoff. A separate charger was used to charge the vehicle's 12-volt accessory battery.

The charger efficiency test data for the 72LE26ET battery charger are presented in table V and in figure 11. The indicated efficiencies of the charger, as calculated from the readings on the residential kilowatt-hour meter and the average values of charger output voltages and current, are in close agreement with the efficiencies that were calculated from the wattmeter readings. The wattmeter efficiency calculations are slightly higher. Since the power efficiency is fairly constant over the entire charging time, the energy efficiency is approximately equal to the average of the power efficiencies.

Battery

<u>Manufacturer's data</u>. - The battery supplied with the Hummingbird was made up of 12 Trojan J-217W golf car batteries connected in series. Each is a three-cell, 6-volt monobloc. The manufacturer rates the battery at 135 ampere-hours when discharged at 75 amperes (108-min rate) to 1.75 volts per cell at 80° F. Other manufacturer's data are presented in table VI.

<u>Battery acceptance</u>. - Two battery acceptance tests were conducted: a 300-ampere discharge terminal integrity test, and a battery capacity test.

The 300-ampere test was performed on an electronic load bank. Terminal temperatures were measured with temperature-sensitive tape. None of the terminals exceeded the 60° C temperature rise criteria. Therefore, the vehicle battery passed the test.

The capacity test was also run on the electronic load bank. The vehicle battery was discharged at a 75-ampere rate until the voltage dropped to 1.75 volts per cell. This voltage was reached after 98 minutes (122 Ah) of continuous discharge, which is 90 percent of the battery rating of 135 ampere-hours. Since the capacity of the battery must be greater than 80 percent of rated capacity, the battery passed the capacity test.

Road test battery performance. - Battery test data for all the vehicle track tests are shown in table VII. The capacity in ampere-hours removed from the battery varied from 103 ampere-hours to 131 ampere-hours. The overcharge based on ampere-hours varied from 74 percent to 34 percent. The battery temperature rise varied extensively from 9° C to 37° C. The specific gravity of the battery electrolyte before the test ranged from 1.260 to 1.286, which dropped to about 1.135 after the test.

Battery charging. - Figure 12 is a typical charging curve for the Hummingbird vehicle battery charger. Presented are the average current, voltage, and power returned to the battery after the 40-kilometer-per-hour (25-mph) range test performed on 4/21/77. The charge was terminated at a battery voltage of 93 volts (2.58 volts per cell) when the current was 7.3 amperes. The total capacity of the battery as calculated from the data was 185 ampere-hours, which compares favorably with the measured data presented in table VII. The total energy input to the battery was 15.5 kilowatt-hours.

Controller

The Hummingbird is controlled by the EVC-500-72 controller manufactured by the Semiconductor Division of Electric Vehicle Components, Inc. (EVC). This controller uses a high-current switching transistor in a chopper circuit. Pulse width modulation at 400 hertz provides motor speed control from 0 to 100 percent. Battery output current is multiplied at startup and during acceleration. Efficiency is greater than 98 percent.

Motor

The Hummingbird motor was manufactured by Kaylor Energy Products and was originally designed for use as an aircraft generator. It was converted to a conventional series-wound traction motor that is rated at 7.5 kilowatts (10 hp) at 3000 rpm, 500 amperes, and 72 volts.

VEHICLE RELIABILITY

No major problems were encountered that prevented completion of the tests. Several problems delayed the tests, and one problem necessitated altering the test program. The original charger furnished with the vehicle failed early in the program while charging the battery. It was replaced by a new unit. The controller also had to be modified to provide greater cooling airflow in order to prevent motor overheating at high speeds. The cooling fan on the controller had to be replaced after a blade failed during a test. The maximum speed of the vehicle was reduced 8 kilometers per hour (5 mph) below that determined from the shakedown test because the motor overheated at 64 kilometers per hour (40 mph).

DRIVER REACTION AND VEHICLE SERVICEABILITY

The Volkswagen "Thing" was originally designed as a utilty vehicle and its design does not emphasize passenger comfort. The Hummingbird was operated with higher tire pressures than the Volkswagen. This and the zero-zero wheel alignment contributed to a poor ride and adversely affected the vehicle handling.

Acceleration and constant-speed operation was smooth. However, the 4-speed transaxle was not matched to the motor. This resulted in slow acceleration and overheating of the motor under certain operating conditions.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 **Vehicle manufacturer** Electric Passenger Cars, Inc.
San Diego, California

2.0 **Vehicle** EPC Hummingbird

3.0 **Price and availability** ______

4.0 **Vehicle weight and load**

4.1	Curb weight, kg (lbm)	1191 (2625)
4.2	Gross vehicle weight, kg (lbm)	1463 (3225)
4.3	Cargo weight, kg (lbm)	none
4.4	Number of passengers	4
4.5	Payload, kg (lbm)	272 (600)

5.0 **Vehicle size**

5.1	Wheelbase, m (in.)	2.40 (94.5)
5.2	Length, m (in.)	3.78 (149)
5.3	Width, m (in.)	1.64 (64.5)
5.4	Height, m (in.)	
5.5	Head room, m (in.)	1.12 (44)
5.6	Leg room, m (in.)	0.76 (30)
5.7	Frontal area, m^2 (ft^2)	2.23 (24)
5.8	Road clearance, m (in.)	
5.9	Number of seats	2 bucket, front; 1 bench, rear

6.0 **Auxiliaries and options**

6.1 Lights (number, type, and function) 2 head; 4 park and turn; 2 rear brake and reverse incorporated; rear license; instrument

6.2 Windshield wipers dual electric; 2 speed

6.3 Windshield washers yes, normal

6.4 Defroster no

6.5 Heater no

6.6 Radio no

6.7 Fuel gage no

6.8 Amperemeter yes, 600 A

6.9 Tachometer no

6.10 Speedometer yes, 0 - 160 km/h (0 - 100 mph)

6.11 Odometer yes

6.12 Right- or left-hand drive left

6.13 Transmission 4 speeds forward, 1 reverse; manual

6.14 Regenerative braking no

6.15 Mirrors 1 safety interior; 2 outside

6.16 Power steering no

6.17 Power brakes no

6.18 Other

7.0 Battery

7.1 Propulsion battery

7.1.1 Type and manufacturer Trojan J-217W, lead acid, 6 volt

7.1.2 Number of modules 12

7.1.3 Number of cells 36

7.1.4 Operating voltage, V 72

7.1.5 Capacity, Ah 217 (20-h rate)

7.1.6 Size of each module, m (in.) 0.27×0.18×0.27 (10.5×7×10.5)

7.1.7 Weight, kg (lbm)

7.1.8 History (age, number of cycles, etc.) unknown

7.2 Auxiliary battery

7.2.1 Type and manufacturer Astro-lite commercial

7.2.2 Number of cells 6

7.2.3 Operating voltage, V 12

7.2.4 Capacity, Ah

7.2.5 Size, m (in.) 0.25×0.17×0.20 (10×6.75×8)

7.2.6 Weight, kg (lbm)

8.0 Controller

8.1 Type and manufacturer 500-72; EVC

8.2 Voltage rating, V 72

8.3 Current rating, A 400 (current limited)

8.4 Size, m (in.) 0.27×0.15×0.15 (10.5×6×6)

8.5 Weight, kg (lbm) 2.3 (5)

9.0 Propulsion motor

9.1 Type and manufacturer modified aircraft generator; Kaylor Energy Products

9.2 Insulation class

9.3 Voltage rating, V

9.4 Current rating, A 500

9.5 Horsepower (rated), kW (hp) 7.5 (10)

9.6 Size, m (in.) diam, 0.30 (12); length, 0.36 (14)

9.7 Weight, kg (lbm)

9.8 Speed (rated), rpm 3000

10.0 Battery charger

10.1 Type and manufacturer 72LE26ET; Lester Equipment Manufacturing Co., Inc.

10.2 On- or off-board type off board

10.3 Input voltage required, V 230/208

10.4 Peak current demand, A 30 (26 rated)

10.5 Recharge time, h 12

10.6 Size, m (in.) 0.38×0.27×0.33 (15×10.5×13)

10.7 Weight, kg (lbm) 34.5 (76)

10.8 Automatic turnoff feature yes

11.0 Body

11.1 Manufacturer and type Volkswagen "Thing"

11.2 Materials steel

11.3 Number of doors and type 4 entrance detachable; motor access rear; battery access front

11.4 Number of windows and type 4 slip on door; 1 rear; 1-piece windshield

11.5 Number of seats and type 2 bucket, front; 1 bench, rear

11.6 Cargo space volume, m^3 (ft^3) ____

11.7 Cargo space dimensions, m (ft) ____

12.0 Chassis

12.1 Frame

12.1.1 Type and manufacturer 1974 Volkswagen "Thing"

12.1.2 Materials steel

12.1.3 Modifications none

12.2 Springs and shocks

12.2.1 Type and manufacturer heavy-duty telescopic

12.2.2 Modifications none

12.3 Axles

12.3.1 Manufacturer Volkswagen

12.3.2 Front standard

12.3.3 Rear standard transaxle

12.4 Transmission

12.4.1 Type and manufacturer Volkswagen

12.4.2 **Gear ratios** first, 3.80; second, 2.06; third, 1.26; fourth, 0.93; reverse, 3.88

12.4.3 **Driveline ratio** 4.125

12.5 Steering

12.5.1 **Type and manufacturer** conventional with damper; Volkswagen

12.5.2 **Turning ratio** ______

12.5.3 **Turning diameter, m (ft)** 11 (36)

12.6 Brakes

12.6.1 **Front** drum

12.6.2 **Rear** drum

12.6.3 **Parking** hand-operated cable to rear

12.6.4 **Regenerative** no

12.7 Tires

12.7.1 **Manufacturer and type** Goodrich radial

12.7.2 **Size** 185SR14

12.7.3 **Pressure, kPa (psi):**

Front 276; rated 221 (40; rated 32)

Rear 276; rated 221 (40; rated 32)

12.7.4 **Rolling radius, m (in.)** left, 0.3183 (12.53); right, 0.3162 (12.45)

12.7.5 **Wheel weight, kg (lbm):**

Without drum 17.9 (39.5)

With drum ______

12.7.6 **Wheel track, m (in.):**

Front ______

Rear ______

13.0 Performance

13.1 **Manufacturer-specified maximum speed (wide-open throttle), km/h (mph)** 64 (40)

13.2 **Manufacturer-recommended maximum cruise speed (wide-open throttle), km/h (mph)** 64 (40)

13.3 **Tested at cruise speed, km/h (mph)** 64 (40); 56 (35)

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

The test track used to conduct the tests described in this report is located in Phoenix, Arizona. The track is owned and operated by Dynamic Science a subsidiary of Talley Industries.

The test track is a paved, continuous two-lane, 3.2-kilometer- (2-mile-) long oval with an adjacent 40 000-square-meter (10-acre) skid pad. The inner lane of the track is not banked and was used for all cycle tests and all constant-speed tests of 56 kilometers per hour (35 mph) or under. The outer lane has zero lateral acceleration at 80 kilometers per hour (50 mph) and was used for tests over 56 kilometers per hour (35 mph). An elevation survey of the track is shown in figure C-1. Average grade is 0.66 percent on the northern straight section and 0.76 percent on the southern straight section. The surface of the track and skid pad is asphaltic concrete with a dry locked-wheel skid number of 82 and a wet locked-wheel skid number of 71.

Wet and dry braking-in-turn tests were conducted on the skid pad. Wet recovery tests were conducted on the test track after driving through the wet-brake water trough located near the northern straight section of the track. Both 20- and 30-percent grades are available for parking brake tests.

APPENDIX C

VEHICLE PREPARATION AND TEST PROCEDURE

Vehicle Preparation

When a vehicle was received at the test track, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle preparation check sheet, such as the one shown in figure C-1. The vehicle was examined for physical damage when it was removed from the transport truck and before it was accepted from the shipper. Before the vehicle was operated, a complete visual check was made of the entire vehicle including wiring, batteries, motor, and controller. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight (GVW) was determined from the vehicle sticker GVW. If the manufacturer did not recommend a GVW, it was determined by adding 68 kilograms (150 lbm) per passenger plus any payload weight to the vehicle curb weight.

The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The battery was charged and specific gravities taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals was checked by drawing either 300 amperes or the vehicle manufacturer's maximum allowed current load from the battery through a load bank for 5 minutes. If the temperature of the battery terminals or interconnections rose more than 60 degrees Celsius above ambient, the test was terminated and the terminal was cleaned or the battery replaced. The batteries were then recharged and a battery capacity check was made. The battery was discharged in accordance with the battery manufacturer's recommendations. To pass this test, the capacity must be within 20 percent of the manufacturer's published capacity at the published rate.

The vehicle manufacturer was contacted for his recommendations concerning the maximum speed of the vehicle, tire pressures, and procedures for driving the vehicle. The vehicle was photographed head-on with a 270-millimeter telephoto lens from a distance of about 30.5 meters (100 ft) in order to determine the frontal area.

Test Procedure

Each day, before a test, a test checklist was used. Two samples of these checklists are shown in figure C-2.

The first item under driver instructions on the test checklist is to complete the pretest checklist (fig. C-3).

Data taken before, during, and after each test were entered on the vehicle data sheet (fig. C-4). These data include

(1) Average specific gravity of the battery

(2) Tire pressures

(3) Fifth-wheel tire pressure

(4) Test weight of the vehicle

(5) Weather information

(6) Battery temperatures

(7) Time the test was started

(8) Time the test was stopped

(9) Ampere-hours out of the battery

(10) Fifth-wheel distance count

(11) Odometer readings before and after the tests

The battery charge data taken during the charge cycle were also recorded on this data sheet. These data include the average specific gravity of the battery after the test, the kilowatt-hours and ampere-hours put into the battery during the charge, and the total time of the charge.

To prepare for a test, the specific gravities were first measured for each cell and recorded. The tire pressures were measured and the vehicle was weighed. The weight was brought up to the GVW by adding sandbags. The instrumentation was connected, and power from the instrumentation battery was applied. All instruments were turned on and warmed up. The vehicle was towed to the starting point on the track. The fifth-wheel distance counter and ampere-hour integrator counter were reset to zero, and thermocouple reference junctions were turned on. The test was started and was carried out in accordance with the test checklist. When the test was terminated, the vehicle was brought to a stop and the post-test checks were made in accordance with the post-test checklist (fig. C-5). The driver recorded on the vehicle data sheet the time, the odometer reading, the ampere-hour integrator reading, and the fifth-wheel distance reading. At the end of the test, weather data were recorded on the vehicle data sheet. All instrumentation power was turned off, the instrumentation battery was disconnected, and the fifth wheel was raised. The vehicle was then towed back to the garage, the post-test specific gravities were measured for all cells and the vehicle was placed on charge.

After the test, the engineer conducting the test completed a test summary sheet (fig. C-6). This data sheet provides a brief summary of the pertinent information received from the test. Another data sheet, the engineer's data sheet (fig. C-7), was also filled out. This data sheet summarizes the engineer's evaluation of the test and provides a record of problems, malfunctions, changes to instrumentation, etc., that occurred during the test.

Weather data. - Wind speed and direction and ambient temperature were measured at the beginning and at the end of each test and every hour during the test. The wind anemometer was located about 1.8 meters (6 ft) from the ground near the southern straight section of the track. The ambient temperature readings were taken at the instrumentation trailer near the west curve of the track. During most of the test period the winds were variable and gusty.

Determination of maximum speed. - The maximum speed of the vehicle was determined in the following manner. The vehicle was fully charged and loaded to gross vehicle weight. After one warmup lap, the vehicle was driven at wide-open throttle for three laps around the track. The minimum speed for each lap was recorded and the average was calculated. This average was called the vehicle maximum speed. This speed takes into account track variability and maximum vehicle loading. This quantity was then reduced by 5 percent and called the recommended maximum cruise test speed.

Cycle timer. - The cycle timer (fig. C-8) was designed to assist the vehicle driver in accurately driving SAE schedules B, C, and D. The required test profile is permanently stored on a programmable read-only memory (PROM), which is the heart of the instrument. This profile is continuously reproduced on one needle of a dual-movement analog meter shown in the figure. The second needle is connected to the output of the fifth wheel and the driver "matches needles" to accurately drive the required schedule.

One second before each speed transition (e.g., acceleration to cruise or cruise to coast), an audio signal sounds to forewarn the driver of a change. A longer duration audio signal sounds after the idle period to emphasize the start of a new cycle. The total number of test cycles driven is stored in a counter and can be displayed at any time with a pushbutton (to conserve power).

REFERENCES

1. Sargent, Noel B.; Maslowski, Edward A.; Soltis, Richard F.; and Schuh, Richard M.: Baseline Tests of the C. H. Waterman DAF Electric Passenger Vehicle. NASA TM-73757, 1977.

2. Society of Automotive Engineers, Inc.: Electric Vehicle Test Procedure - SAE J227a. Feb. 1976.

TABLE I. - SUMMARY OF TEST RESULTS FOR EPC HUMMINGBIRD[a]

(a) SI units

Test date	Test condition (constant speed, km/h; or driving schedule)	Wind velocity, km/h	Air temperature, °C	Range, km	Cycle life, number of cycles	Capacity out of batteries, Ah	Capacity into batteries, Ah	Energy into charger, MJ	Indicated energy consumption, MJ/km
3/26/77	40	5 - 8	6	43.3	--	114.6	194.2	19.1	1.59
3/27/77	50	5 - 10	7	36.2	--	103.4	159.8	15.5	1.54
3/28/77	B	5 - 16	10	32.2	93	121.7	162.8	16.5	1.86
4/14/77	B	11	24	32.8	98	121.0	209.8	19.9	2.19
4/20/77	50	14	28	37.3	--	109.2	181.8	17.4	..68
4/21/77	40	6	30	63.2	--	131.3	183.1	17.1	.98
4/25/77	40	13	32	59.5	--	130.5	191.7	18.2	1.10

(b) U.S. customary units

Test date	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Air temperature, °F	Range, miles	Cycle life, number of cycles	Capacity out of batteries, Ah	Capacity into batteries, Ah	Energy into charger, kWh	Indicated energy consumption, kWh/mile
3/26/77	25	3 - 5	43	26.9	--	114.6	194.2	19.1	0.71
3/27/77	35	3 - 6	45	22.5	--	103.4	159.8	15.5	.69
3/28/77	B	3 - 9	50	20.0	93	121.7	162.8	16.5	.83
4/14/77	B	7	75	20.4	98	121.0	209.8	19.9	.98
4/20/77	35	9	82	23.2	--	109.2	181.8	17.4	.75
4/21/77	25	4	86	39.3	--	131.3	183.1	17.1	.44
4/25/77	25	8	90	37.0	--	130.5	191.7	18.2	.49

[a]Problems encountered during tests:
3/29/77 - Motor overheated during 64-km/h (40-mph) range test.
4/15/77 - Cooling fan failed during maximum acceleration test.

TABLE II. - ACCELERATION AND GRADEABILITY OF EPC HUMMINGBIRD

(a) At full battery charge

Vehicle speed		Time to reach designated vehicle speed, s	Acceleration		Gradeability, percent
km/h	mph		m/s^2	mph/s	
0	0	0	0	0	0
2.0	1.2	.6	.90	2.02	9.3
4.0	2.5	1.2	.94	2.10	9.7
6.0	3.7	1.8	1.06	2.36	10.9
8.0	5.0	2.3	1.14	2.55	11.8
10.0	6.2	2.8	1.15	2.58	11.9
12.0	7.5	3.3	1.20	2.69	12.4
14.0	8.7	3.7	1.24	2.78	12.9
16.0	9.9	4.1	1.17	2.61	12.0
18.0	11.2	4.6	1.23	2.95	12.7
20.0	12.4	5.1	1.37	3.06	14.2
22.0	13.7	5.5	1.17	2.61	12.0
24.0	14.9	6.0	.86	1.92	8.8
26.0	16.2	6.8	.69	1.55	7.1
28.0	17.4	7.7	.55	1.24	5.7
30.0	18.7	8.8	.45	1.02	4.7
32.0	19.9	10.1	.42	.95	4.3
34.0	21.1	11.4	.35	.77	3.5
36.0	22.4	13.6	.25	.56	2.6
38.0	23.6	15.9	.31	.69	3.1
40.0	24.9	17.4	.41	.91	4.2
42.0	26.1	18.6	.45	1.01	4.6
44.0	27.4	19.9	.42	.94	4.3
46.0	28.6	21.3	.40	.89	4.1
48.0	29.8	22.7	.35	.78	3.6
50.0	31.1	24.6	.26	.59	2.7
52.0	32.3	26.9	.22	.50	2.3
54.0	33.6	29.6	.17	.37	1.4
56.0	34.8	34.1	.15	.33	1.5
58.0	36.1	37.3	.14	.32	1.5
60.0	37.3	42.1	.14	.30	1.4
62.0	38.5	45.7	.16	.36	1.6
64.0	39.8	49.0	.17	.38	1.8
66.0	41.0	52.3	.16	.35	1.6
68.0	42.3	56.3	.11	.24	1.1
70.0	43.5	63.8	.08	.18	.8
72.0	44.8	70.5	.08	.17	.8
74.0	46.0	78.2	.06	.14	.6

(b) At 40-percent battery discharge

Vehicle speed		Time to reach designated vehicle speed, s	Acceleration		Gradeability, percent
km/h	mph		m/s^2	mph/s	
0	0	0	0	0	0
2.0	1.2	.6	.96	2.14	9.9
4.0	2.5	1.2	.96	2.14	9.8
6.0	3.7	1.7	.99	2.20	10.2
8.0	5.0	2.3	1.05	2.34	10.8
10.0	6.2	2.8	1.10	2.46	11.3
12.0	7.5	3.3	1.05	2.36	10.9
14.0	8.7	3.9	.95	2.12	9.7
16.0	9.9	4.5	.86	1.93	8.9
18.0	11.2	5.2	.78	1.77	8.1
20.0	12.4	5.9	.69	1.55	7.1
22.0	13.7	6.8	.57	1.27	5.8
24.0	14.9	7.9	.44	.98	4.5
26.0	16.2	9.4	.36	.81	3.7
28.0	17.4	11.0	.31	.70	3.2
30.0	18.7	12.9	.24	.54	2.5
32.0	19.9	15.8	.24	.53	2.4
34.0	21.1	17.8	.33	.74	3.4
36.0	22.4	19.2	.41	.92	4.2
38.0	23.6	20.5	.40	.88	4.1
40.8	24.9	22.1	.32	.71	3.3
42.0	26.1	24.0	.29	.64	3.0
44.0	27.4	26.0	.25	.55	2.5
46.0	28.6	28.7	.18	.39	1.8
48.0	29.8	32.5	.15	.33	1.5
50.0	31.1	36.3	.13	.29	1.3
52.0	32.3	41.3	.17	.37	1.7
54.0	33.6	43.8	.21	.47	2.1
56.0	34.8	46.7	.19	.42	1.9
58.0	36.1	49.7	.17	.37	1.7
60.0	37.3	53.4	.14	.31	1.4
62.0	38.5	57.9	.10	.23	1.0

TABLE II. - Concluded.

(c) At 80-percent battery discharge

Vehicle speed		Time to reach designated vehicle speed, s	Acceleration		Gradeability, percent
km/h	mph		m/s^2	mph/s	
0	0	0	0	0	0
2.0	1.2	.7	.86	1.92	8.8
4.0	2.5	1.3	.88	1.98	9.1
6.0	3.7	2.0	.80	1.79	8.2
8.0	5.0	2.7	.71	1.58	7.3
10.0	6.2	3.5	.64	1.44	6.6
12.0	7.5	4.4	.58	1.30	6.0
14.0	8.7	5.4	.53	1.18	5.4
16.0	9.9	6.5	.48	1.08	5.0
18.0	11.2	7.8	.42	.94	4.3
20.0	12.4	9.2	.33	.79	3.4
22.0	13.7	11.2	.25	.57	2.6
24.0	14.9	13.6	.19	.42	1.9
26.0	16.2	17.7	.13	.29	1.3
28.0	17.4	22.2	.24	.54	2.5
30.0	18.7	23.7	.35	.77	3.5
32.0	19.9	25.4	.32	.71	3.3
34.0	21.1	27.2	.29	.66	3.0
36.0	22.4	29.2	.24	.54	2.5
38.0	23.6	32.0	.17	.38	1.8
40.0	24.9	35.8	.13	.29	1.3
42.0	26.1	40.6	.09	.21	1.0
44.0	27.4	48.4	.09	.21	.9
46.0	28.6	53.3	.12	.26	1.2
48.0	29.8	58.0	.11	.25	1.1

TABLE III. - ROAD ENERGY CONSUMPTION AND ROAD POWER REQUIREMENTS

OF EPC HUMMINGBIRD

Vehicle speed		Time, s	Road energy consumed		Road power required	
km/h	mph		MJ/km	kWh/mile	kW	hp
76.0	47.2	0	0	0	0	0
74.0	46.0	2.3	.348	.156	7.16	9.60
72.0	44.7	4.7	.340	.152	6.80	9.12
70.0	43.5	7.0	.421	.188	8.18	10.97
68.0	42.3	8.7	.506	.226	9.56	12.82
66.0	41.0	10.3	.458	.205	8.39	11.25
64.0	39.8	12.3	.441	.197	7.83	10.50
62.0	38.5	14.0	.479	.214	8.24	11.05
60.0	37.3	15.7	.451	.201	7.51	10.07
58.0	36.0	17.6	.424	.190	6.83	9.17
56.0	34.8	19.5	.412	.184	6.40	8.59
54.0	33.6	21.6	.358	.160	5.37	7.20
52.0	32.3	24.1	.377	.168	5.44	7.30
50.0	31.8	26.0	.369	.165	5.13	6.88
48.0	29.8	28.7	.321	.144	4.28	5.74
46.0	28.6	31.1	.321	.144	4.10	5.50
44.0	27.3	33.8	.308	.138	3.76	5.04
42.0	26.1	36.4	.286	.128	3.33	4.47
40.0	24.9	39.5	.261	.117	2.90	3.89
38.0	23.6	42.6	.253	.113	2.67	3.58
36.0	22.4	45.9	.245	.110	2.45	3.29
34.0	21.1	49.2	.242	.108	2.28	3.06
32.0	19.9	52.7	.227	.101	2.01	2.70
30.0	18.6	56.4	.221	.098	1.84	2.46
28.0	17.4	60.1	.212	.094	1.65	2.21
26.0	16.2	64.1	.212	.095	1.53	2.05
24.0	14.9	67.8	.218	.098	1.45	1.95
22.0	13.7	71.5	.202	.090	1.23	1.65
20.0	12.4	75.9	.163	.073	.91	1.22
18.0	11.2	81.8	.138	.062	.69	.92
16.0	9.9	87.7	.139	.062	.62	.83
14.0	8.7	93.5	.141	.063	.55	.74
12.0	7.5	99.2	.149	.067	.50	.67
10.0	6.2	104.4	.151	.068	.42	.56
8.0	5.0	109.9	.152	.068	.34	.45
6.0	3.7	115.1	.146	.065	.24	.33
4.0	2.5	121.2	.140	.063	.16	.21

TABLE IV. - ENERGY CONSUMPTION FOR

EPC HUMMINGBIRD

Vehicle speed		Energy consumption	
km/h	mph	MJ/km	kWh/mile
40.2	25.0	1.633	0.730
40.2	25.0	1.275	.570
40.2	25.0	.962	.430
56.3	35.0	1.544	.690
56.3	35.0	1.454	.650
56.3	35.0	1.678	.750

TABLE V. - CHARGER EFFICIENCY TEST DATA FOR EPC HUMMINGBIRD

Elapsed time, h	Power in, measured with kWh-meter, kW	Power out, calculated from voltage and current, kW	Power efficiency, percent	Power in	Power out	Energy efficiency, percent
				Measured with wattmeter		
				kW	kW	
0	2.64	2.28	86	2.59	2.33	90
1.0	2.59	2.25	87	2.54	2.29	90
2.0	2.58	2.25	87	2.53	2.26	89
2.5	2.42	2.14	88	2.40	2.16	90
2.75	1.97	1.73	88	1.96	1.80	92
3.0	1.61	1.41	88	1.55	1.46	94
3.25	1.25	1.20	96	1.29	1.23	95
3.5	1.03	.942	91	1.04	.992	95
3.75	.916	.866	94.5	.95	.89	93.6

TABLE VI. - CHARACTERISTICS OF TROJAN J-217W ELECTRIC

VEHICLE BATTERY MODULES USED IN EPC HUMMINGBIRD

Module length, m (in.)	0.26 (10.375)
Module width, m (in.)	0.18 (7.063)
Module height, m (in.)	0.29 (11.500)
Module weight, kg (lbm):	
Dry	23 (50)
Wet	30 (66)
Electrolyte volume, liter (qt)	5.7 (6)
Specific gravity at full charge	1.260±0.005
Rating, Ah:	
At 75 A (108-min rate) to 1.75 VPC	135
20-h rate	217

TABLE VII. - BATTERY TEST DATA FOR EPC HUMMINGBIRD

Test condition (constant speed or driving schedule)		Test date	Battery capacity, Ah		Amount of overcharge, percent	Electrolyte specific gravity		Average battery temperature, °C	
km/h	mph		Input	Output		Before test	After test	Before test	After test
40	25	3/26/77	194	115	69	1.269	1.125	24	34
56	35	3/27/77	160	103	55	1.273	1.138	34	38
B		3/28/77	163	122	34	1.277	1.130	26	34
40	25	4/11/77	163	122	34	1.277	1.130	26	34
56	35	4/12/77	184	111	66	1.270	1.140	32	38
B		4/14/77	210	121	74	1.275	1.135	--	35
56	35	4/20/77	182	109	67	1.286	1.140	32	46
40	25	4/21/77	183	131	40	1.289	1.138	31	41
40	25	4/25/77	192	131	47	1.267	1.140	--	--

Figure 1. - EPC Hummingbird electric passenger vehicle.

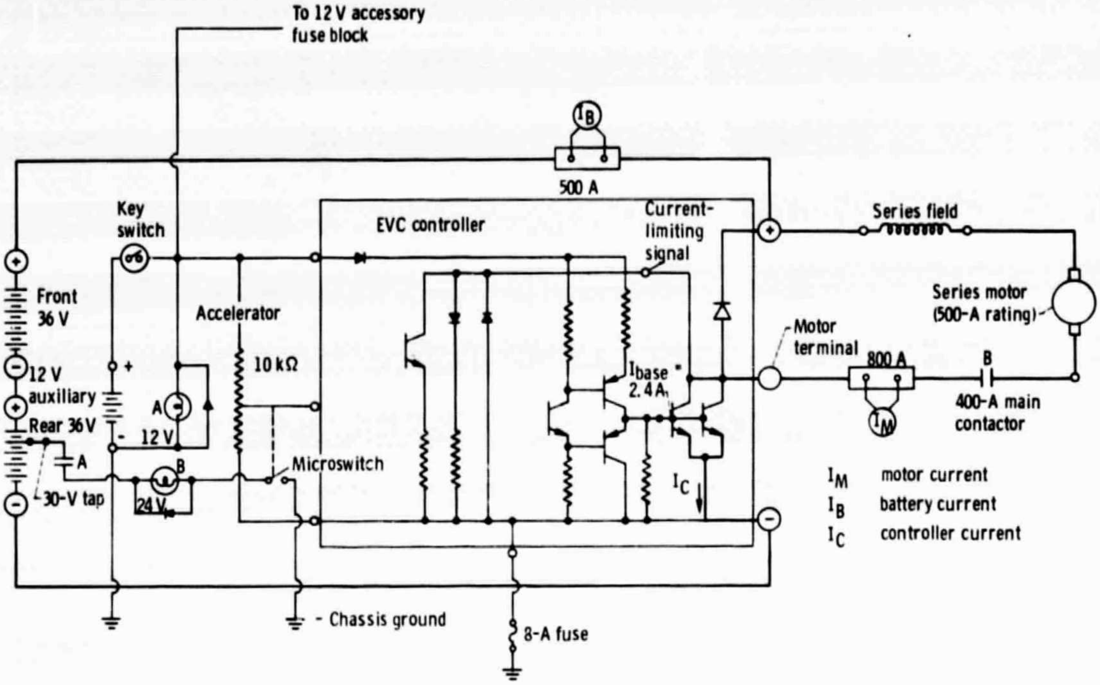
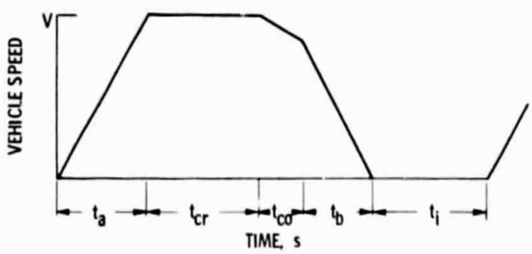


Figure 2. - Wiring and instrumentation layout for EPC Hummingbird.



TEST PARAMETER	SAE SCHEDULES		
	B	C	D
MAX. SPEED, V, mph	20	30	45
ACCEL. TIME, t_a, s	19	18	28
CRUISE TIME, t_{cr}	19	20	50
COAST TIME, t_{co}	4	8	10
BRAKE TIME, t_b	5	9	9
IDLE TIME, t_i	25	25	25

Figure 3. - SAE J227a driving cycle schedules.

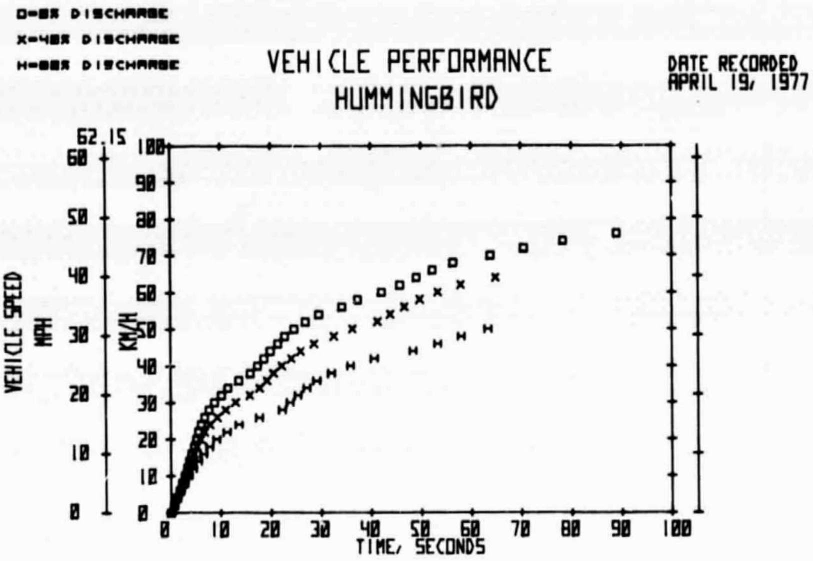


Figure 4. - Vehicle acceleration.

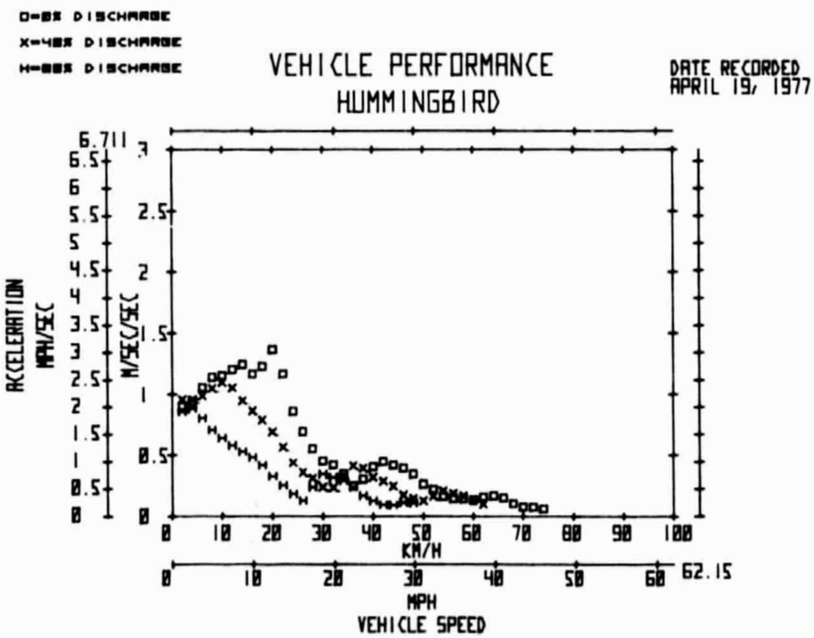


Figure 5. - Acceleration as a function of speed.

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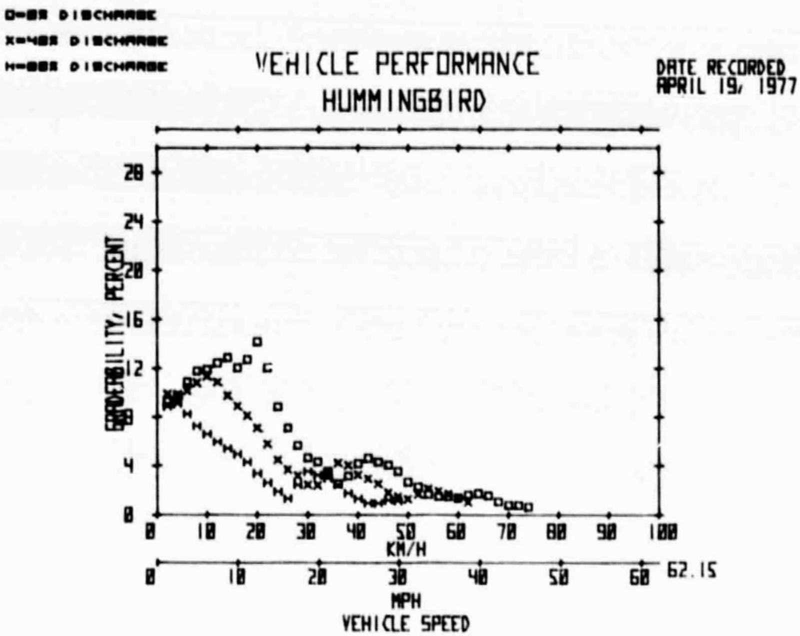

Figure 6. - Gradeability as a function of speed.

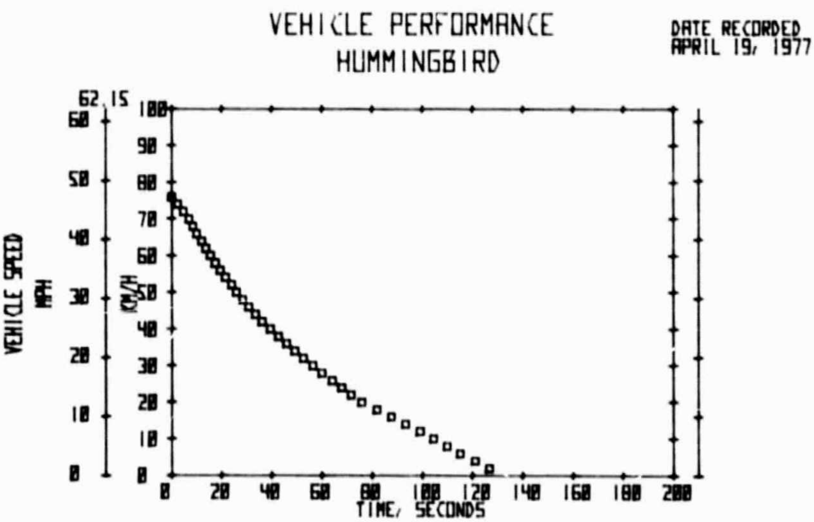

Figure 7. - Vehicle deceleration.

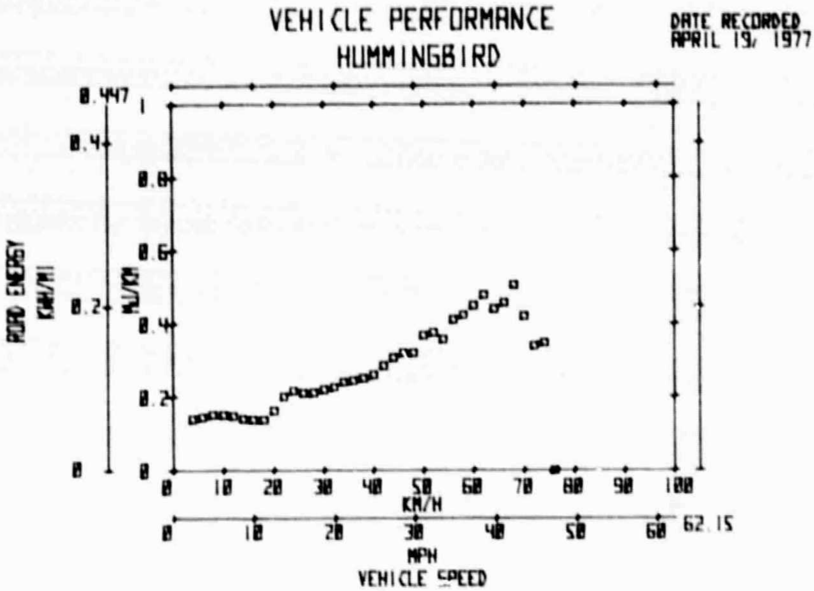

Figure 8. - Road energy as a function of speed.

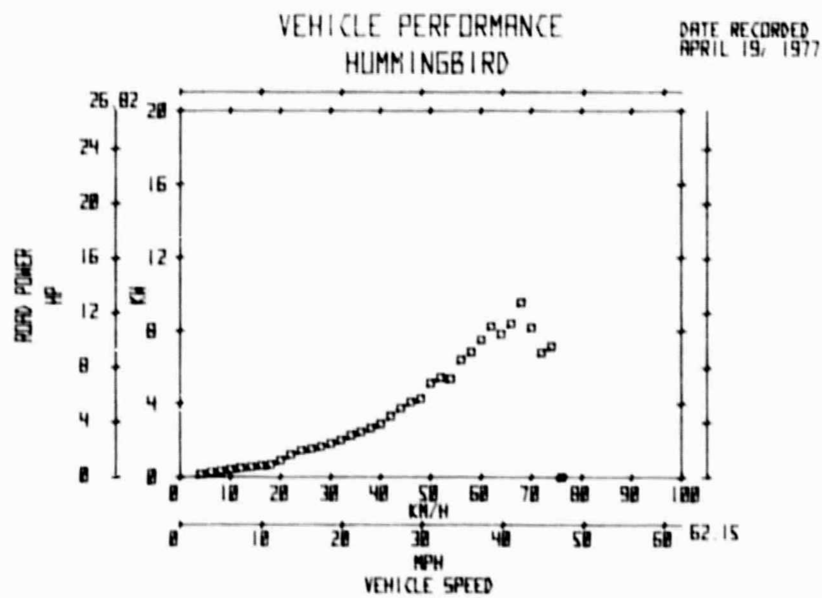

Figure 9. - Road power as a function of speed.

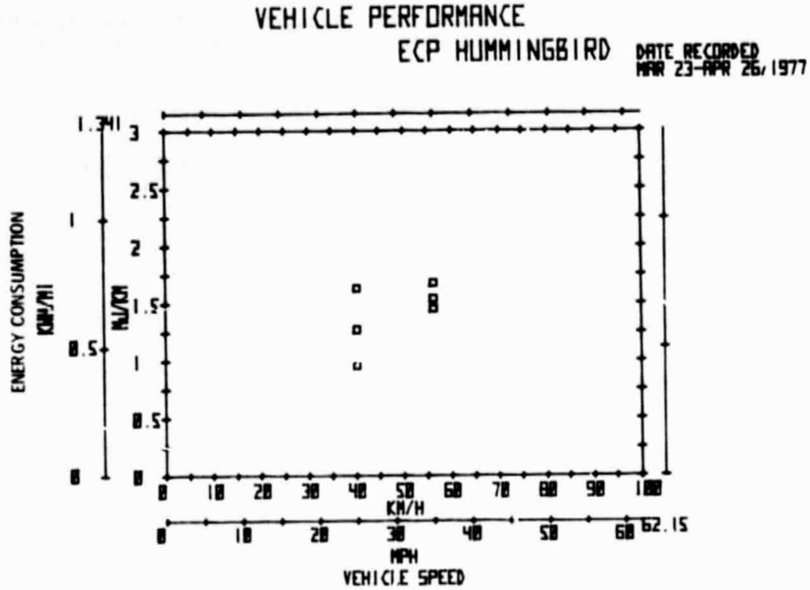

Figure 10. - Energy consumption as a function of speed.

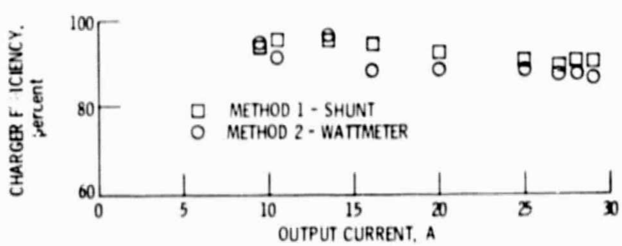

Figure 11. - Charger efficiency for EPC Hummingbird's 72LE26ET Lester charger.

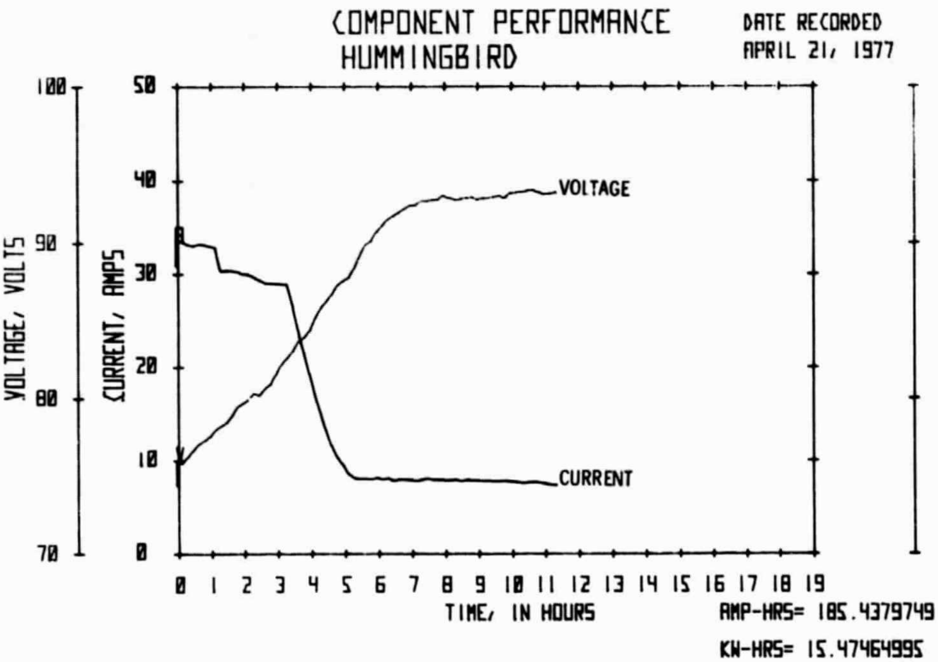

Figure 12. - Battery charger output.

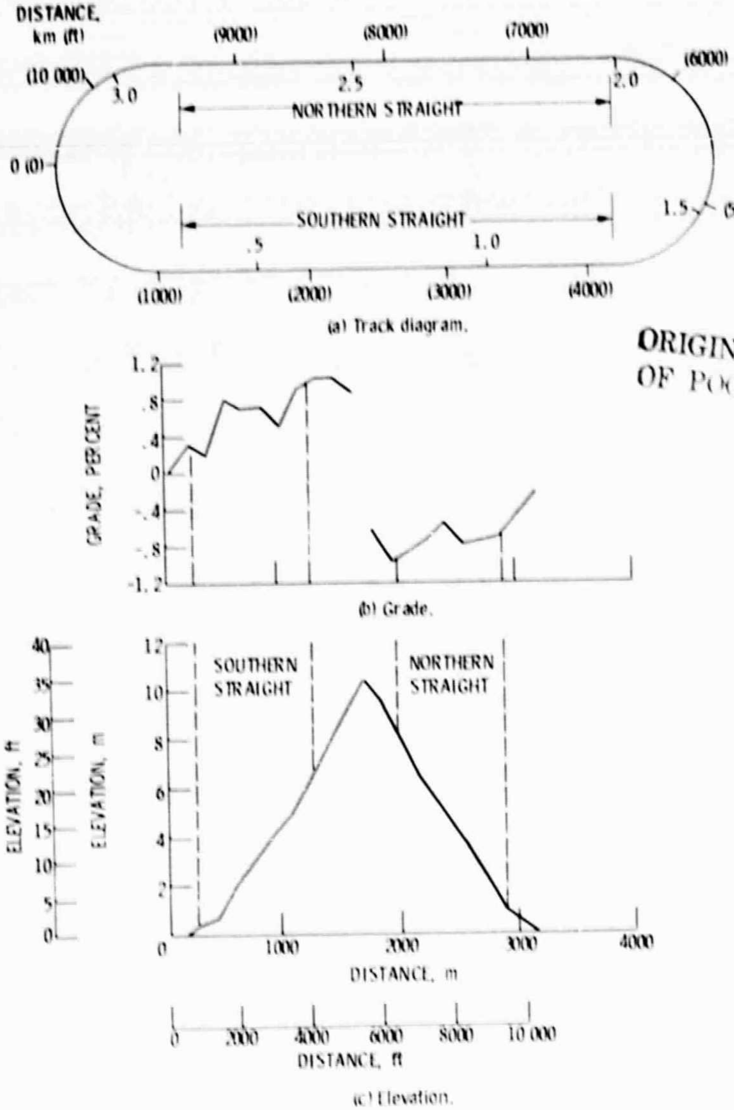

Figure B-1. - Characteristics of Dynamic Science Test Track, Phoenix, Arizona.

1. Vehicle __________
2. Date received __________
3. Checked for damage - date __________
4. Wheel alignment - date __________
5. Battery checked and equalized - date __________
6. Curb weight determined, lbm __________ Date __________
7. Gross vehicle weight, lbm __________
8. 300-Ampere test - date __________
9. Manufacturers recommendations:
   - Maximum speed, mph __________
   - Tire pressures, psi: Front __________; Rear __________
   - Driving procedures __________

Figure C-1. - Vehicle preparation check sheet.

Vehicle ____________________, ____________ mph range test, ____________ gear

Driver Instructions:

1. Complete pretest checklist.
2. While on track recheck:
   Integrator - light on, in "operate" position, zeroed
   Speedometer - set on ____ mph center
   Distance - on, reset, lighted
   Attenuator - on, reset, lighted
3. At signal from control center accelerate moderately to ____ mph.
4. Maintain ____ ±1 mph with minimal accelerator movement.
5. When vehicle is no longer able to maintain ____ mph, brake moderately to full stop.
6. Complete post-test checklist and other documentation.

Recording:

1. Set oscillograph zeros at:

Channel	Zero, in.
3	3.0
4	4.5
6	5.0
10	.75
12	1.1
13	1.2
14	2.0

2. Record all channels on magnetic tape. Check inputs at beginning of test to verify recording.
3. Run cals on all channels.
4. Remove all channels from oscillograph except 3 and 4.
5. Start recording 15 s before start of test at oscillograph speed of 0.1 in/s and tape speed of ______ in/s.
6. After 15 min into test connect channels 6, 10, 12, 13, and 14 to oscillograph and record a burst at 100 in/s while vehicle is in chopper mode.
7. Remove channels 6, 10, 12, 13, and 14 from oscillograph and continue test at 0.1 in/s with channels 3 and 4 only.
8. Document all ambient conditions at beginning, once every hour, and at the end of the test. Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure.

(a) Constant-speed test.

Vehicle ____________________, ____________ cycle test, ____________ gear

Driver Instructions:

1. Complete pretest checklist.
2. While on track recheck:
   Integrator - light on, in "operate" position, zeroed
   Speedometer - set on ____ mph center
   Distance - on, reset, lighted
   Attenuator - on, reset, selector on 100
   Cycle timer - verify scheduled timing with stop watch
3. At signal from control center, perform cycle test using cycle timer as basis for determining length of each phase of performance cycle. Use programmed stop watch as backup device. Cycle consists of
   Accelerate to ______ mph in ______ s
   Cruise at ______ mph for ______ s
   Coast for ______ s
   Brake to complete stop in ______ s
   Hold in stop position for ______ s
   Repeat entire cycle until vehicle is unable to meet acceleration time. Moderately brake to a complete stop.
4. Complete post-test checklist and other documentation.

Recording:

1. Record all channels on magnetic tape at ______ in/s. Check all channels to verify input at beginning of test.
2. Record speed and distance on oscillograph at ______ in/s.
3. Start recording data 15 s before beginning test.
4. Document ambient conditions at beginning, once every hour, and at the end of the test. Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure.

(b) Driving cycle test.

Figure C-2. - Test checklists

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1. Record specific gravity readings after removing vehicle from charge, and disconnect charger instrumentation. Fill in charge data portion of data sheet from previous test. Add water to batteries as necessary, recording amount added. Check and record 5th wheel tire pressure and vehicle tire pressure.

2. Connect: (Connect alligator clips to instrumentation battery last)
   (a) Inverter to instrument battery
   (b) Integrator input lead
   (c) Integrator power to inverter
   (d) Starred (*) 5th wheel jumper cable
   (e) Cycle timer power and speed signal input cables. Check times.
   (f) Spin up and calibrate 5th wheel

3. Record test weight - includes driver and ballast with 5th wheel raised.

4. Turn on:
   (a) Inverter, motor speed sensor, thermocouple reference junctions, integrator, and digital voltmeter. Set integrator on "Operate."
   (b) Fifth wheel readout and switching interface units (2). (Select distance for expanded scale range.)

5. Tow vehicle onto track with 5th wheel raised.
   Precalibrations:
   - Tape data system
   - Oscillograph

   Reset:
   - 5th wheel distance
   - Ampere-hour meter
   - Thermocouple readout switches on "Record"

   Turn on thermocouple reference junctions.
   Lower 5th wheel. Set hub loading.

6. Be sure data sheet is properly filled out to this point. Check watch time with control tower.

7. Proceed with test.

Figure C-3. - Pretest checklist.

Vehicle ____________ Battery system ____________
Test ____________ Date ____________
Track data:
Driver ____________ Navigator ____________
Average pretest specific gravity ____________
Open-circuit voltage, V ____________
Tire pressure before test, psi:
Right front ___ Left front ___ Right rear ___ Left rear ___
Tire pressure after test, psi:
Right front ___ Left front ___ Right rear ___ Left rear ___
Fifth-wheel pressure, psi ________ (calibrated, ________ psi)

Weather:	Initial	During test	Final
Temperature, °F	____	____	____
Wind speed, mph	____	____	____
Wind direction	____	____	____
Pressure, in Hg	____	____	____

Battery temperature, °F: Before ________ After ________
Motor temperature, °F: Before ________ After ________

Time: Start ____________ Stop ____________
Odometer reading, miles: Start ________ Stop ________
Current out, Ah ______ Current in (regenerative), Ah ______
Fifth wheel ____________

Basis for termination of tests ____________

Charge data:

Average post-test specific gravity ____________
Open-circuit voltage, V ____________
Charger used ____________
Charger input voltage, V ____________
Battery temperature, °F: Before charge ___ After charge ___
Power, kWh: Start ______ End ______ Total ______
Time: Start ____________ End ____________
Total charge time, min ____________
Current input, Ah ____________
Average specific gravity after charge ____________

Approval ____________

Figure C-4. - Track and charge data.

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1. Record time immediately at completion of test. Turn off key switch.
2. Complete track data sheet:
   (a) Odometer stop
   (b) Ampere-hour integrator
   (c) 5th wheel distance
   (d) Read temperature
   (e) Calibrate data system
   (f) Record weather data
3. Turn off inverter, thermocouple reference junctions.
4. Disconnect 12-volt instrument battery red lead.
5. Raise 5th wheel.
6. Tow vehicle off track.
7. Start charge procedure (specific gravities).
8. Check specific gravity on instrument battery. If less than 1.220, remove from vehicle and charge to full capacity.
9. Check water level in accessory batteries. Add water as necessary.

Figure C-5. - Post-test checklist.

Vehicle ____________ Test ____________ Date ____________

Test conditions:

Temperature, ^{o}F ________ Wind speed, mph ________ at ________

Barometer reading, in. Hg ____________; Other ____________

Test results:

Test time, h ____________

Range, miles ____________

Cycles ____________

Current out of battery, Ah ____________

Current into battery, Ah ____________

Charge time, h ____________

Power into battery, kWh ____________

Magnetic tape:

No. ____________; Speed, in/s ____________

Comments ____________

Figure C-6. - Test summary sheet.

Vehicle ____________ Test ____________ Date ____________

Engineer ____________

Reason for test (checkout, component check, scheduled test, etc.) ____________

Limitation on test (malfunction, data system problem, brake drag, etc.) ____________

Changes to vehicle prior to test (repair, change batteries, etc.) ____________

Other comments ____________

Evaluation of test:

Range, miles ____________

Current out, Ah ____________

Current in, Ah ____________

Power in, kWh ____________

Energy consumption, kWh/mile ____________

Was planned driving cycle followed? ____________

General comments ____________

Figure C-7. - Engineer's data sheet.

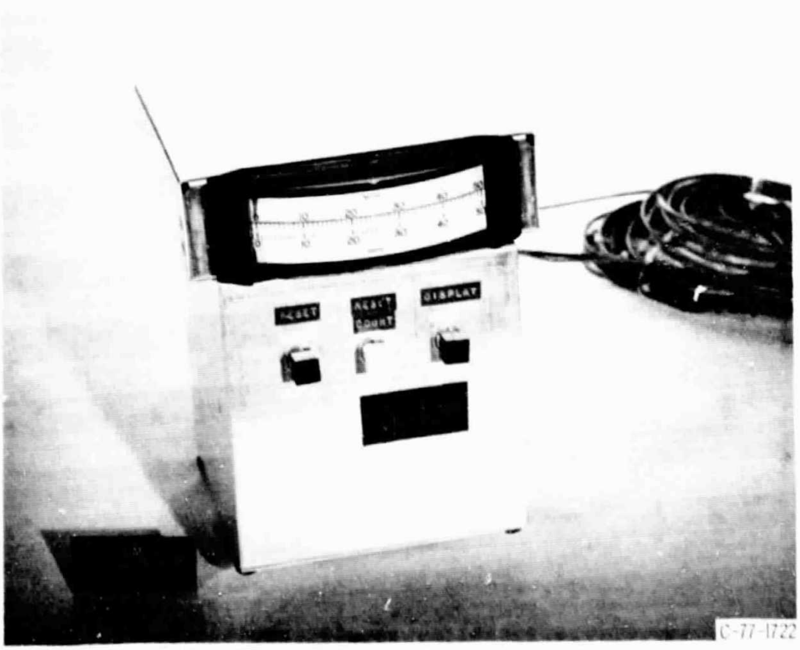

Figure C-8. - Cycle timer.